RF System and RF Transit Phase for muons in MICE

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Introduction

- RF Drive system
  - Revised power distribution network

- Muon – RF Phase determination
  - There is no pre-ordained correlation in MICE between muon arrival and RF phase

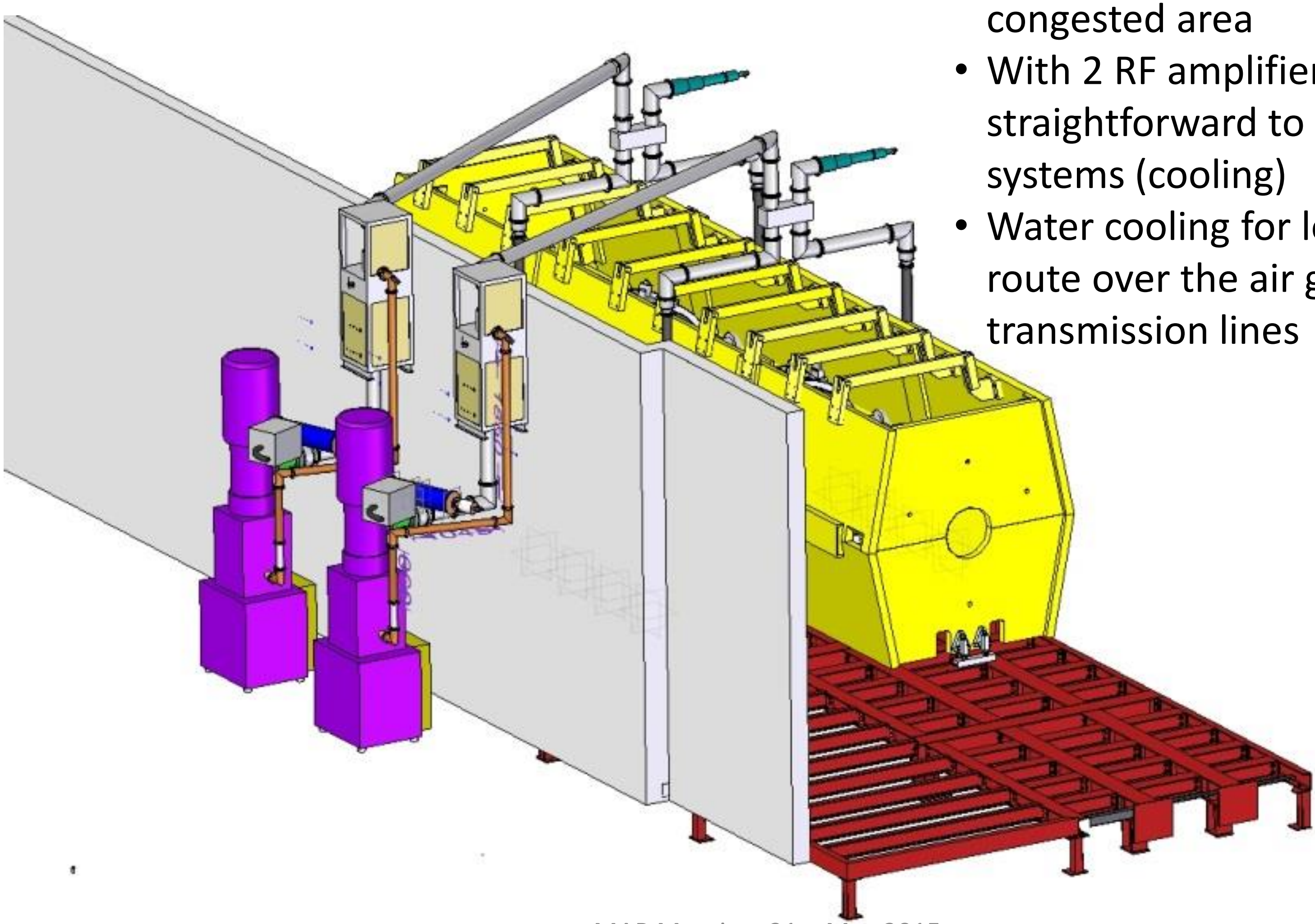
  - Muon 'beam' is extremely tenuous
    - Particles can be measured individually

  - Particle transit time determined by ToF detectors- used in difference measurements
    - ToF resolution ~50ps
    - Time is not directly referenced to external clock
    - Closest ToF is ~2.5m upstream of 1^{st} cavity

  - Cavity transit time inferred by the ToF transit time and the tracker measurement of momentum
    - Tracker resolution, p_z ~ 200MeV/c is Δp_z ~+/-1.3MeV/c
    - For 2.5m gap transit delay is ~9.6ns +/- 60ps

RF network

- Load on each splitter to absorb unbalanced reflections
- Retracted crane hook clears coax over the wall.
- Support from present 'shield wall' and yoke



- 2nd amplifier moved to 3rd position behind wall to ease installation in congested area
- With 2 RF amplifiers now relatively straightforward to place auxiliary systems (cooling)
- Water cooling for load will need to route over the air gap on the transmission lines

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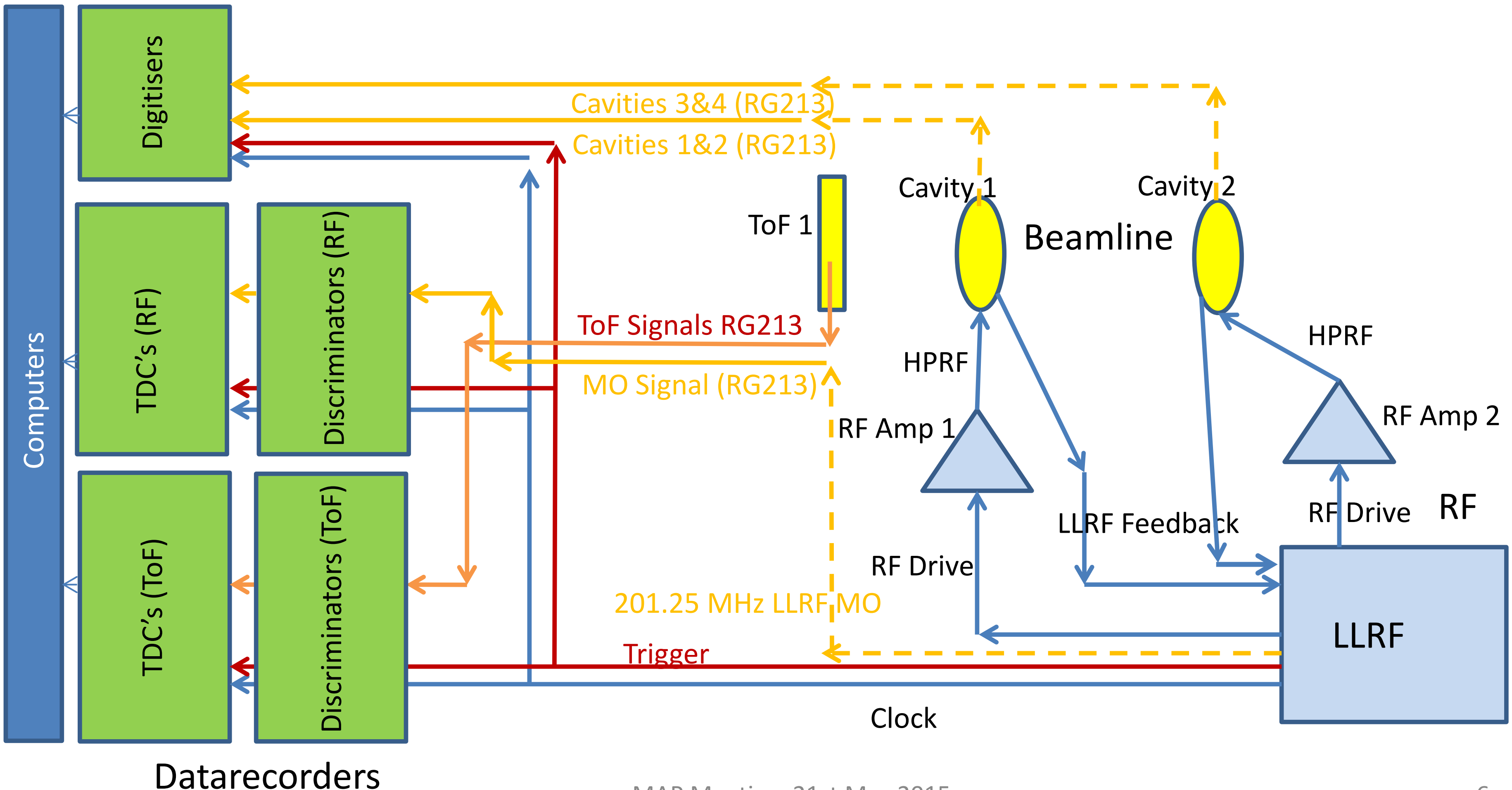
Requirement

- Ionisation cooling is a function of the particle energy
  - The cooling effect is therefore expected to be a function of the acceleration each particle experienced
- Need to be able to select particles for analysis by their RF transit phase
  - Allows the 'bundling' of particles for coherent analysis
  - i.e. As if we are considering the interactions of a real particle 'bunch'
- Particle transit time determined by ToF detectors- used in difference measurements
  - ToF resolution ~50ps
  - Time is not directly referenced to external clock
  - Closest ToF is ~2.5m upstream of 1st cavity
- Cavity transit time inferred by the ToF transit time and the tracker measurement of momentum
  - Tracker resolution, p_z ~ 200MeV/c is Δp_z ~+/-1.3MeV/c
  - For 2.5m gap transit delay is ~9.6ns +/- 70ps
  - Combining ToF resolution and Momentum projection resolution ~ +/- 86ps
  - Desire to know RF phase to better than 0.3 of this ~ 20ps – 30 ps

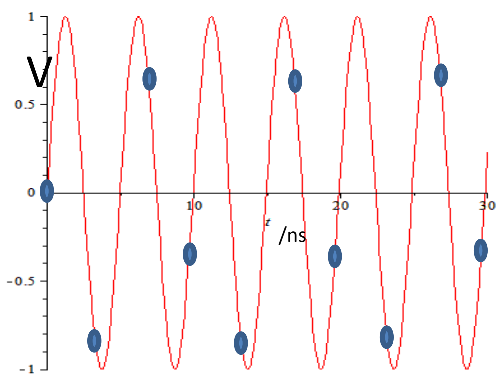
Overview of Timing Critical Elements

- Sketch illustrates relationships of key components
- Two Approaches
  - Digitisation (subsampled) of the RF waveform on the pickup probes
  - TDC recording of the RF waveform of the reference oscillator

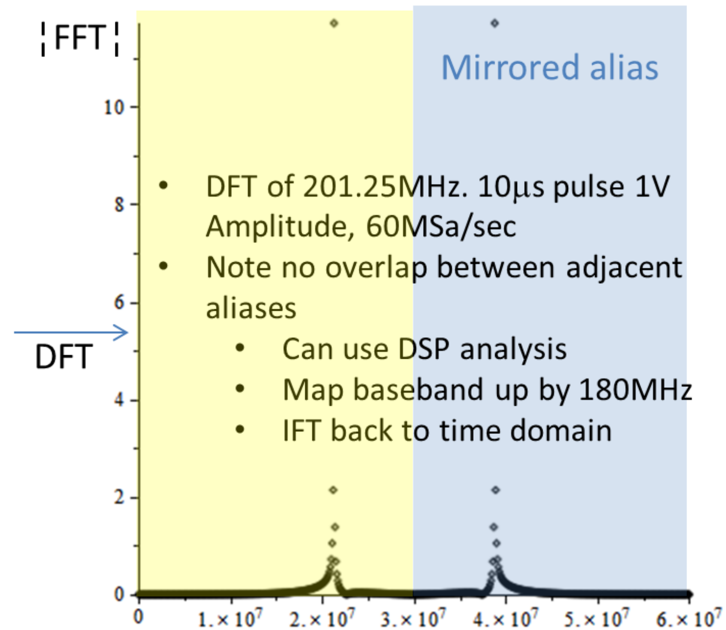


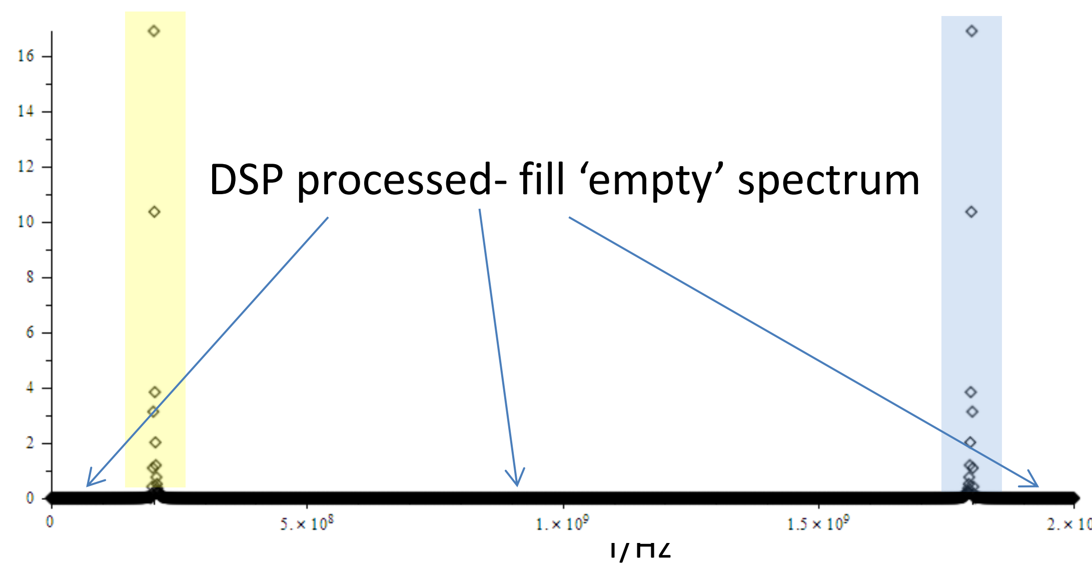
Digitiser subsampling principle

- We know with quite high precision the form of the accelerating field in time
    - 201.25MHz (5kHz width)
    - Do not need to satisfy Nyquist on the signal, only on the bandpass signal



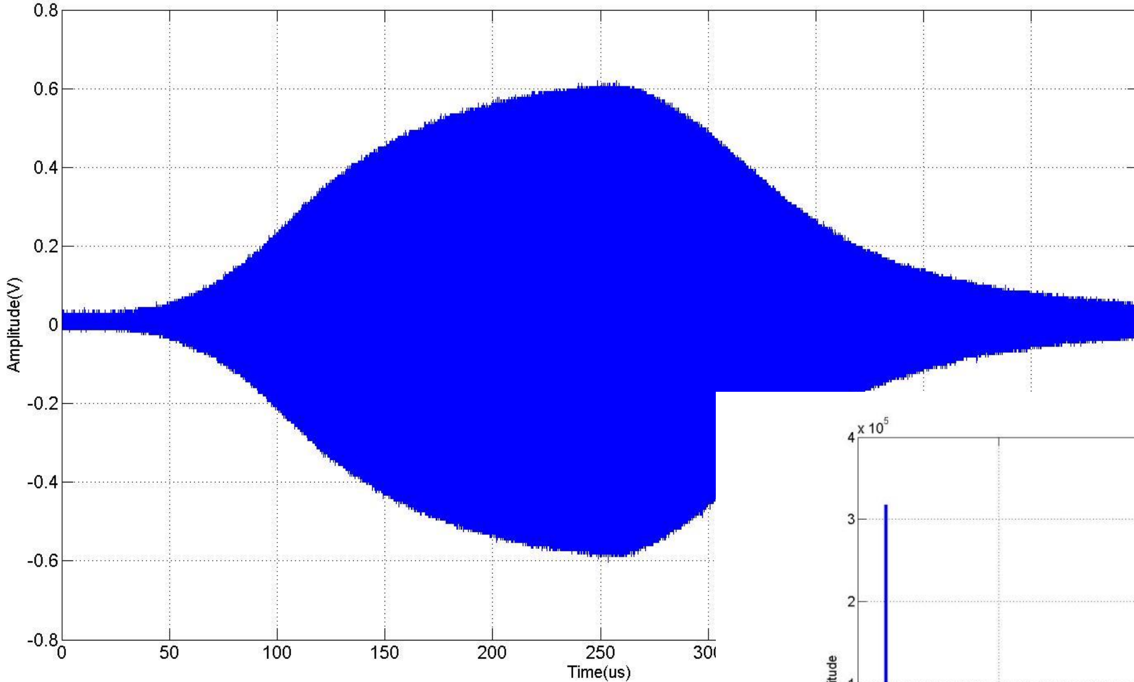
- Now being tested on the cavity pickup signals from the MTA

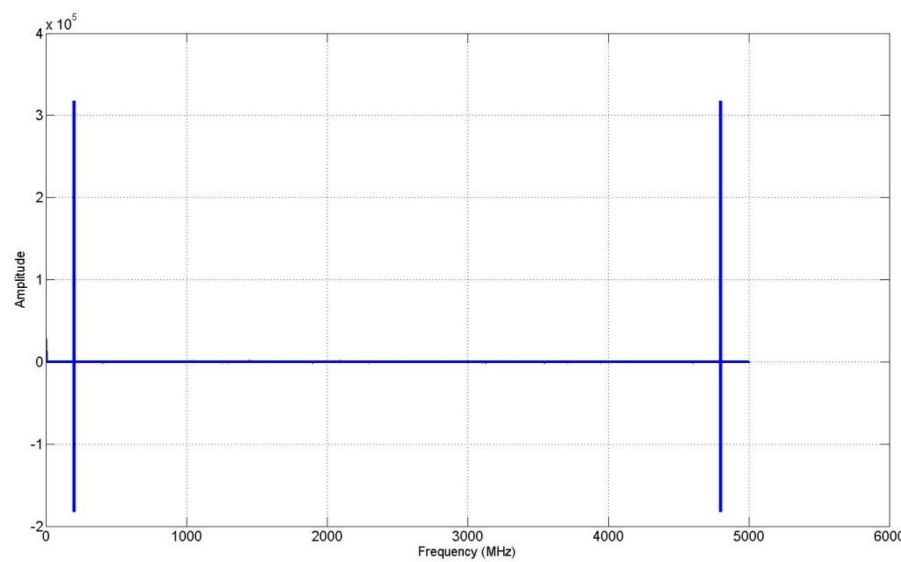




Demonstration of subsample approach

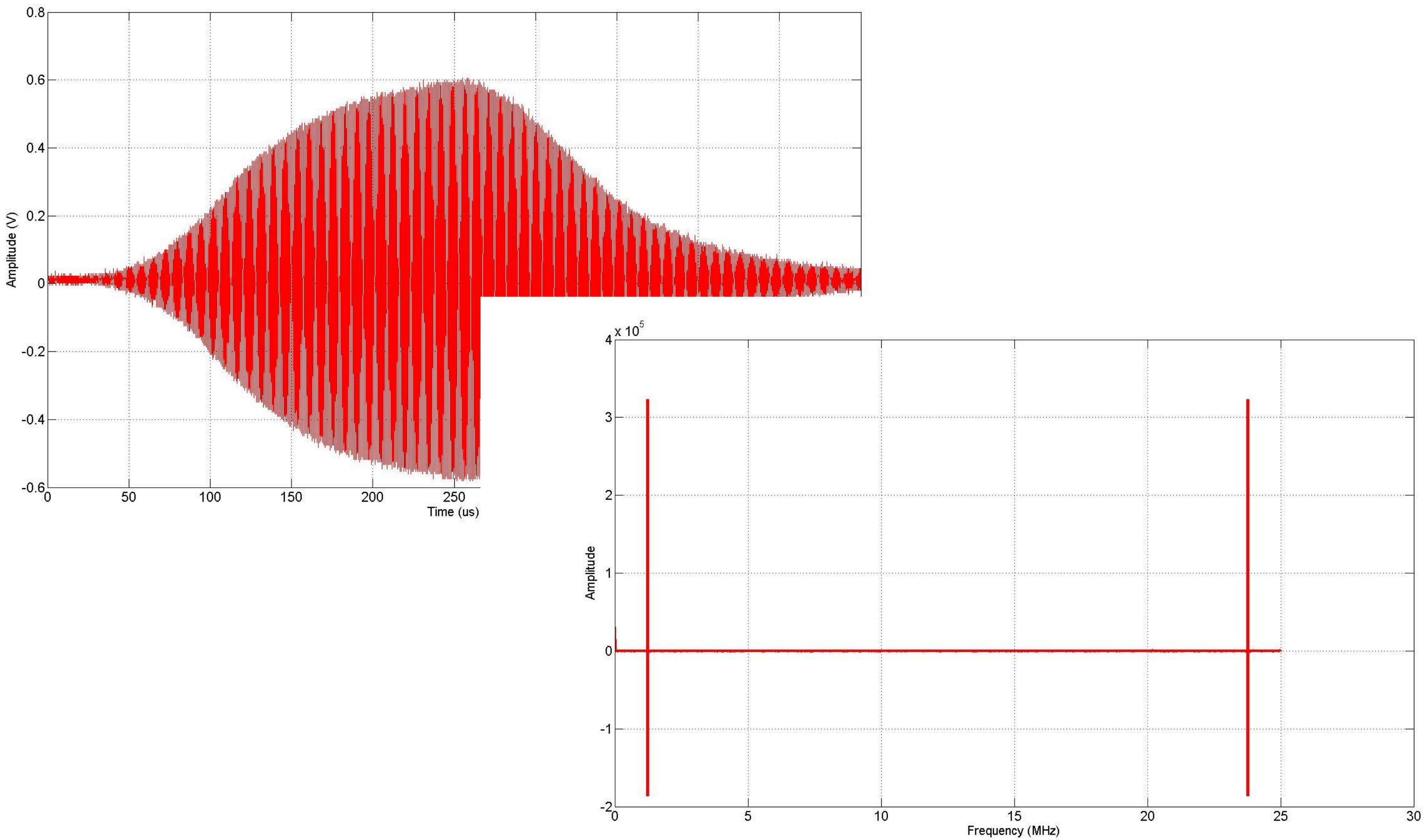
- MTA signals from cavity pickup are ~500μs duration and 201.25MHz (5kHz width)
  - Envelope shown below, Sampled at 5 GSa/sec (Multi MB files- take minutes to save)
    - MICE will be ~ 5 times worse
  - Note- edge ripple is noise and digitiser resolution and precision





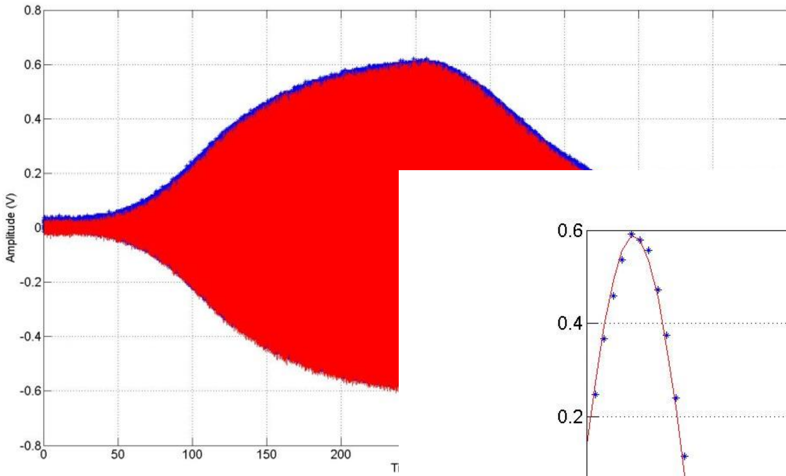
Demonstration of subsample approach

- Subsampling at 25MSa/sec and Fourier Transforming yields 200 times less data ~10's kB

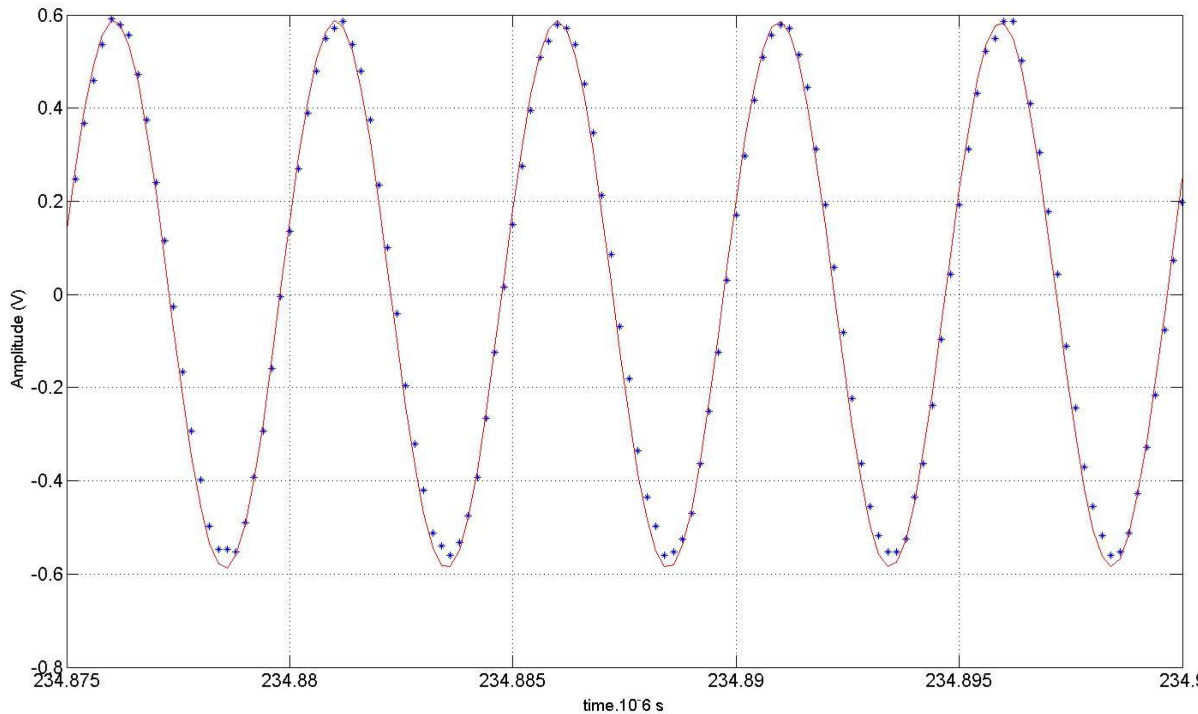


Demonstration of subsample approach

- Reconstructing signal in Fourier domain and comparing signals (Blue is Raw, Red is DSP)



- Note suppression of DC bias
- Note DSP has effective filtered the signal
- Suppressing noise and instrument artefacts



- Zero crossing offsets between Raw and DSP?

Range from 10-75 ps

Not good enough

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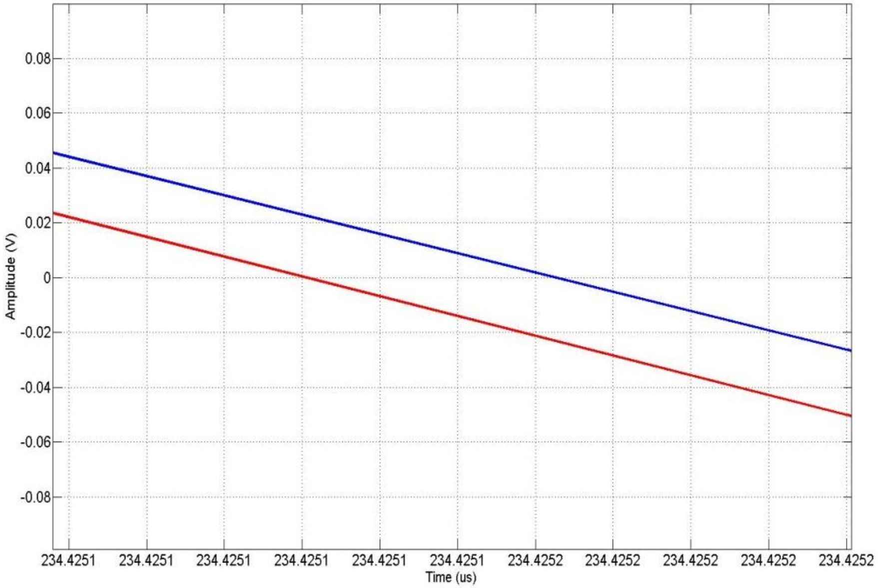

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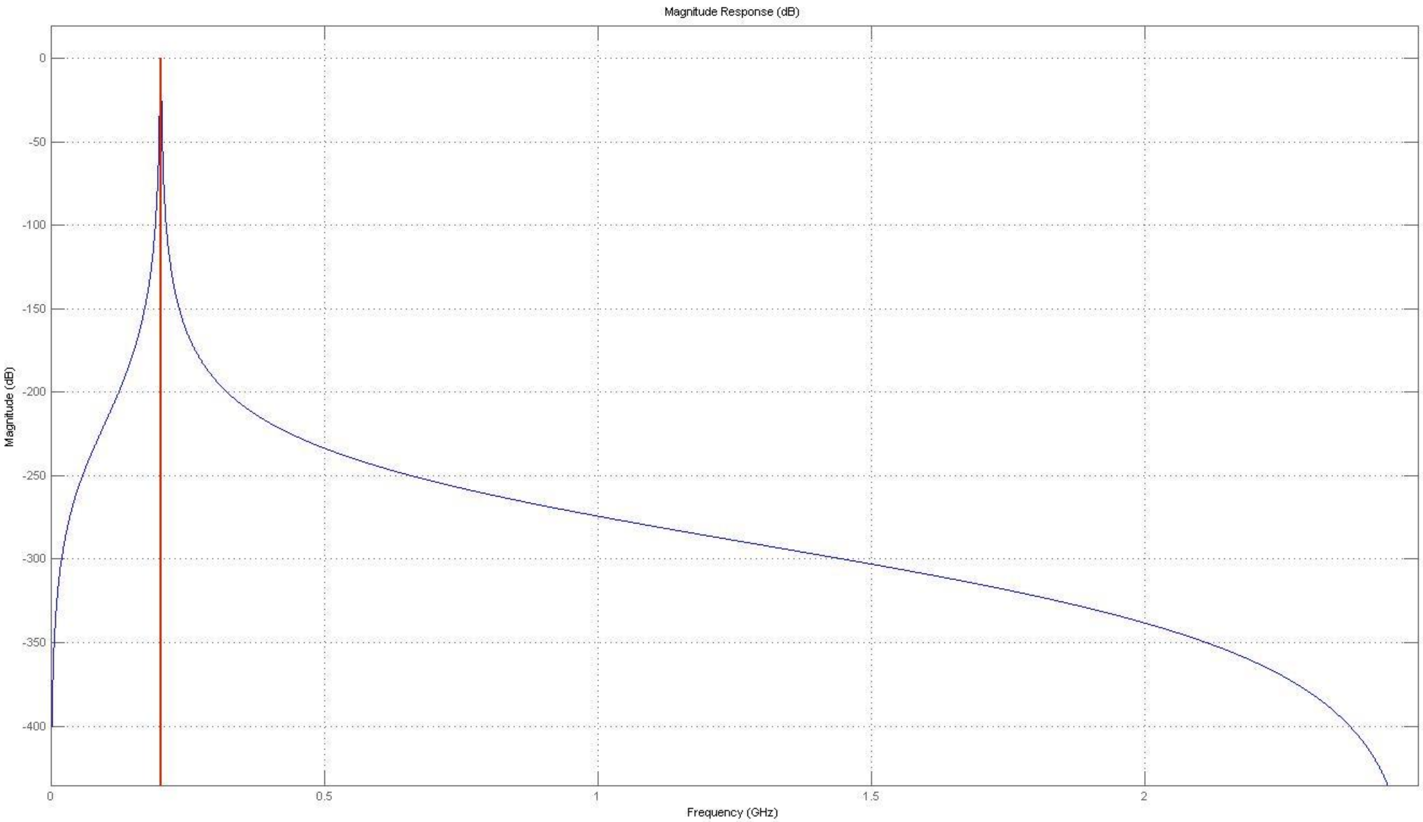
Demonstration of subsample approach

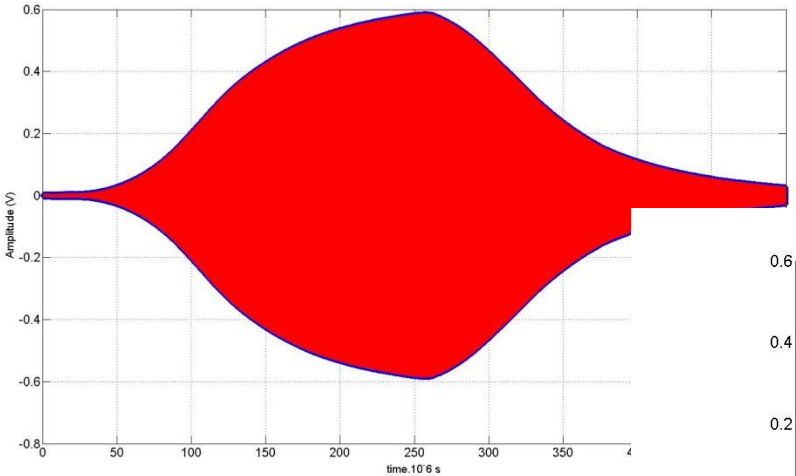
- Problem is not so much with the DSP approach but the digitiser precision and wideband noise in the raw signal- so filter the raw signal

- Butterworth Filter with flat 2MHz passband at 201.25MHz

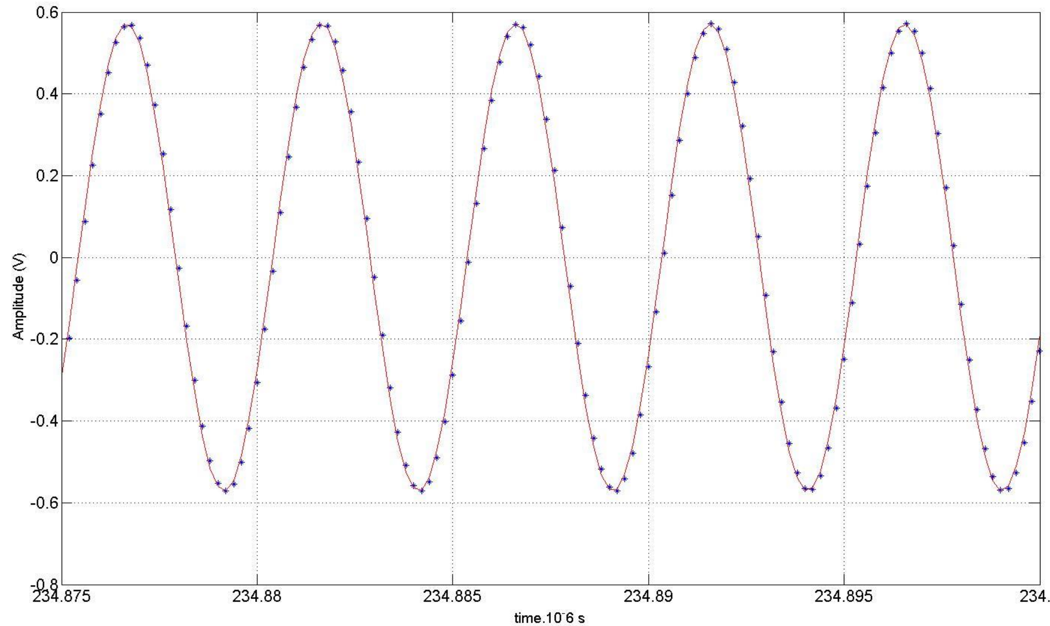


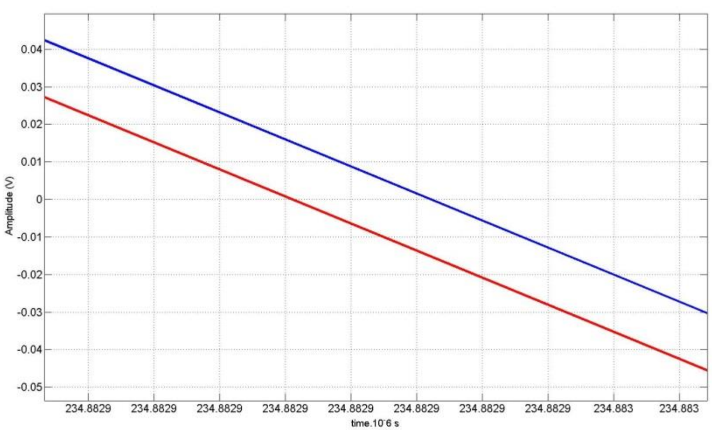
Demonstration of subsample approach

- Reconstructing by DSP gives high fidelity to filtered raw signal- filter completely suppresses the DC offset (blue is Raw, Red is DSP)



- Phase offset appears to be a systematic function of (sub) sample rate
- Random variation ~1ps





Subsample approach

- Appears to work, gives reproduction of filtered real cavity signals from MTA tests
- Can be implemented using VME instruments closely related to our CAEN TDC's
- Need to be able to synchronise timebases with TDC's- at least fix t=0.
  - t=0 can be defined by an external trigger to zero all timebases
  - This could be done just before accelerating gradient reaches maximum

  OR
  - Just before start of RF pulse
  - Use a pulse generator to provide 40MHz clock, and provide trigger by logical AND between clock and trigger pulse- should sync start of timebases
- CAEN V1761 have external clock drive for acquisition rate
  - 10 bit rather than 8 bit units currently recording MTA data
  - Facilitate interfacing with 40MHz clocks of TDC's (requires programming of the clock controller)
  - Need to understand trigger jitter statement?

TDC approach

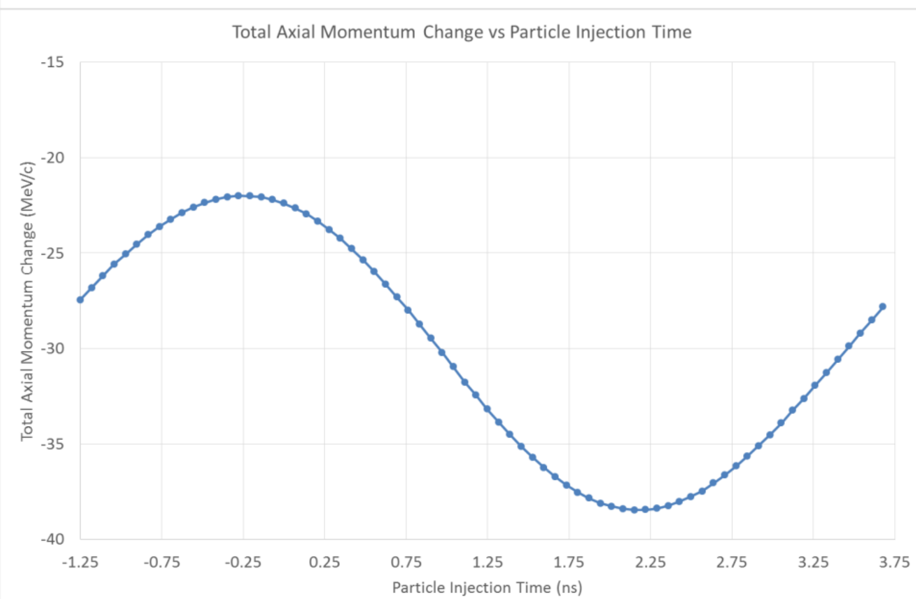
- This will use the TDC (CAEN 1290) currently used to record the ToF's
- RF signal driving discriminators, use TDC time stamps to find cavity 'zero crossings'
  - 25 ps bin size
- Same electronics enhances confidence that any drift in time accuracy will be similar
  - Unfortunately LeCroy discriminators seem problematic at 200MHz
  - Input impedance wanders with frequency, at 201.25MHz, 98+j68Ω
  - Could be matched with L-branch network, but still doesn't fix rate problem
- Ordered two alternative discriminators
  - LeCroy 4608C and LeCroy 2340B
  - Both claim rates well in excess of the present system and have conventional RF input ports
- Discussing requirements with other instrument makers
  - Phillips Scientific and FAST ComTek, 200MHz and 1GHz units respectively
  - Also discussing alternative approach
    - ToF's need CFD's due to variable signals. RF signal has very precise amplitude
    - Really just need threshold detectors- much simpler devices

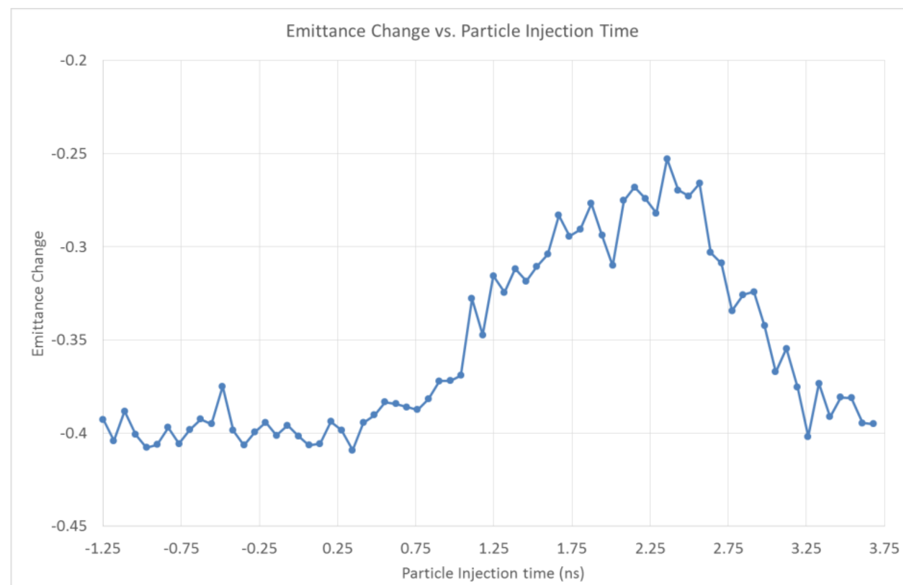
Absolute Calibration

- Providing we can correlate the ToF to the RF with a random variation of <25ps we will not upset the time resolution from the ToF and Trackers
- However both measurements have a number of unknown systematic delays
- It is probably possible to figure these out with high fidelity for the RF system- not clear that all the particle detector systematics can be completely known
- Simple MAUS simulations inject particles at defined entrance time- study effect of entrance time on the change of particle momentum and energy
- Compare to estimates of the tracker resolution and hence infer potential calibration of phase
    - Simulation set up: Input Momentum: 228MeV/c, RF Gradient 10.2MV/m
      Input Emittance 6mm, No. of spills: 200

Axial Energy/Momentum Variation

- Assume the trackers to have a p_z resolution of about+/- 1.4 MeV/c
- Estimate ~ +/- 135ps uncertainty in absolute phase (+/- 2.7% of the cycle, ~ +/- 10^o)
- Emittance reduction flat over this range





Summary

- New RF distribution network planned
  - Overhead rather than underfloor
  - Eases installation interference and timeframes
- Fourier domain reconstruction of signals appears to offer real reduction in data density and reproduces suitably filtered input signals well
  - Need to test filtration in undersampled spectral domain rather than at high rate
- Require to build system to sync triggers of ToF TDC's and digitisers
- Alternative discriminators/threshold detectors required to drive TDC's for TDC approach
  - Instruments awaiting delivery and enquiries to manufacturers
- Simulations indicate likely absolute calibration precision to be ~+/- 130ps